

Methods for Measuring Adult Mortality in Developing Countries: A Comparative Review

Kenneth Hill

Johns Hopkins University

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Abstract

No consensus has emerged on how to estimate adult mortality in countries lacking complete vital registration of deaths and accurate periodic censuses. This paper applies a range of methods to census, registration and survey data for Guatemala for the period from 1981 to 1994. The findings are less than conclusive because of marked errors in the census populations. Methods using intercensal survival perform very poorly, giving rise to results that are hard to interpret. Methods using the distribution of deaths by age and rates of change of the population by age appear to work better, but still give rise to substantially different results. Simulations suggest that a combination of two methods appears to work well. In the Guatemala case, survival of mother appears to over-estimate female adult mortality, whereas survival of siblings appears to underestimate adult mortality. A new method for analyzing intercensal changes in cohort proportions with surviving mother, presented in the paper, gives results broadly consistent with estimates based on adjusted registered deaths.

Introduction

Adult mortality remains poorly measured in many developing countries. Registration of deaths is often incomplete, and even when coverage is adequate, information regarding age is often inaccurate. Census data, needed for denominators of standard rates, are also often of uncertain quality. Considerable ingenuity has been shown in the development of methods to adjust incompletely registered deaths for omission, and of methods to convert indirect indicators of survivorship into standard life table measures. However, wide differences of opinion remain about how well these methods perform, and about overall levels of adult mortality in many developing countries. Uncertainty about these levels is substantially greater than that concerning levels of child mortality or fertility, for both of which both direct and indirect methods exist that have been shown to perform well. In particular, there is no equivalent in adult mortality measurement of the birth history approach to data collection concerning fertility and child mortality.

It has been difficult to validate the performance of many methods to measure adult mortality because there is no “gold standard”. Countries with good registration data do not collect the information needed for the application of indirect methods, and their conventional data do not exhibit the magnitude of potential errors found in many developing country data sets, thus not providing a realistic test of adjustment methods.

The purpose of this paper is to compare the performance of a wide range of methods to data from a country that is widely believed to have largely complete registration of deaths, but has also collected the necessary information for the application of a wide range of indirect methods. Information is available on registered deaths by age and sex for Guatemala for all years from 1983 to 1994. In addition, the 1994 census collected information on household deaths in a reference period from the beginning of 1992 to the date of the 1994 census, as well as on the survival of the mother of each respondent. The 1987 Demographic and Health Survey (DHS) collected information on the survival of each respondent’s mother and father, as well as on whether the mother or the father was alive at the time of her first marriage. The 1995 DHS collected a sibling history for each respondent. In combination with the age distribution of the 1981 census, these data taken together provide a basis for the application of a very wide range of estimation methods.

It might be thought that, because death registration is thought to be close to complete in Guatemala, that the available data provide just the sort of “gold standard” sought for a methodological evaluation. However, problems with the data remain: information on deaths may be affected by systematic age misreporting, and the population censuses of 1981 and 1994 are of uncertain accuracy. Thus in addition to reviewing methods, this paper will attempt to arrive at best estimates of recent levels of adult mortality in Guatemala. The focus will be upon female adult mortality, because it is here that we have the widest availability of relevant data.

Estimation Methods

Methods for estimating adult mortality can be classified into three broad groups: methods based on intercensal survival, methods that assess the completeness of death recording relative to census recording, and methods that convert indicators of mortality levels based on survival of close relatives into standard life table functions. Within each group, there are several different approaches, which are briefly reviewed below.

Intercensal Survival Methods

The mortality risks of successive cohorts can be measured from two censuses. The survivorship ratio from the age group $a, a+5$ at the first census to the corresponding age group $a+t, a+t+5$ at the second census t years later estimates the life table function ${}_5L_{a+t}/{}_5L_a$. These survivorship ratios can be compared to model life table values in order to arrive at an estimate of average post-childhood mortality, or if t is a multiple of 5, successive ratios can be chained together to come up with an estimate of a single summary indicator.

Two census age distributions can also be used as a basis for estimating mortality using intercensal growth rates (Preston and Bennett 1983), and using intercensal growth rates in combination with an assumed “standard” age pattern of mortality (Preston 1983). Although not based on intercensal cohort survival, these methods share with intercensal survival the characteristic that the only empirical information used is two census age distributions.

Assessing the Completeness of Death Recording Relative to Census Enumeration

If the completeness of death recording relative to population recording can be estimated, any differential in completeness can be adjusted for, unbiased death rates calculated, and life table functions calculated. All the methods used assume that coverage completeness is invariant with age, and evaluate completeness of death recording by comparison of the age pattern of deaths with the age pattern of the living. The simplest method further assumes that the population under study is demographically stable (Brass 1975). For any open-ended age segment $a+$ of a closed population, the entry rate into the segment is equal to the growth rate of the segment plus the exit (death) rate of the segment. In a stable population, the growth rate is constant for all segments, so the entry rate and the death rate must be linearly related. If the entry rate is calculated from a population age distribution alone, any coverage error that is invariant with age cancels out, whereas the death rate, calculated from both deaths by age and population by age, will be affected by any differential coverage between population and deaths. The slope of the line relating the entry rate to the exit rate will estimate the completeness of population recording relative to death recording, and provide a potential adjustment factor for the deaths.

This simple method can be generalized when two or more census enumerations are available. Under such circumstances, the growth rate of each segment can be calculated from the census counts, and the assumption of stability is no longer needed. The

relationship of the entry rate minus the growth rate to the death rate, segment by segment, estimates an intercept that captures any change in census coverage between the two censuses, and a slope that estimates the coverage of death recording relative to an average of the coverage of the two censuses (Hill 1987).

Bennett and Horiuchi (1981) propose an alternative way to using two censuses and a distribution of deaths by age. The age-specific growth rates for the intercensal period are used to expand the observed distribution of deaths by age to a stationary population or life table distribution. Since the life table deaths above age a are equal to the life table population of exact age a (since everyone dies), the ratio of expanded deaths above age a to an estimate of the population aged a derived from the two age distributions estimates the completeness of death recording relative to census coverage.

Indirect Methods Based on the Survival of Close Relatives

William Brass developed the first formal methods for converting indicators of mortality based on survival of close relatives into standard life table measures by adjusting for confounders. Brass and Hill (1973) proposed methods for estimating life table survivorship ratios from proportions of respondents of successive five-year age groups with mother alive or father alive. The methods have been improved by several subsequent authors (Hill and Trussell 1977; Timæus 1991, 1992). The age group of respondents represents the survival time of the mother, so the proportion of respondents of a given age group with mother alive approximates a survivorship ratio from an average age of childbearing to that age plus the age of the respondents. The available methods model this relation using different patterns of fertility, mortality and age distribution to allow the conversion of a proportion with parent surviving into a life table survivorship ratio, controlling for the actual age pattern of childbearing. Timæus (1991) has also developed methods for respondents whose mothers died before marriage or after marriage. An Appendix to this paper presents a new way of using information on survival of mother observed for the same cohort of respondents at different time points.

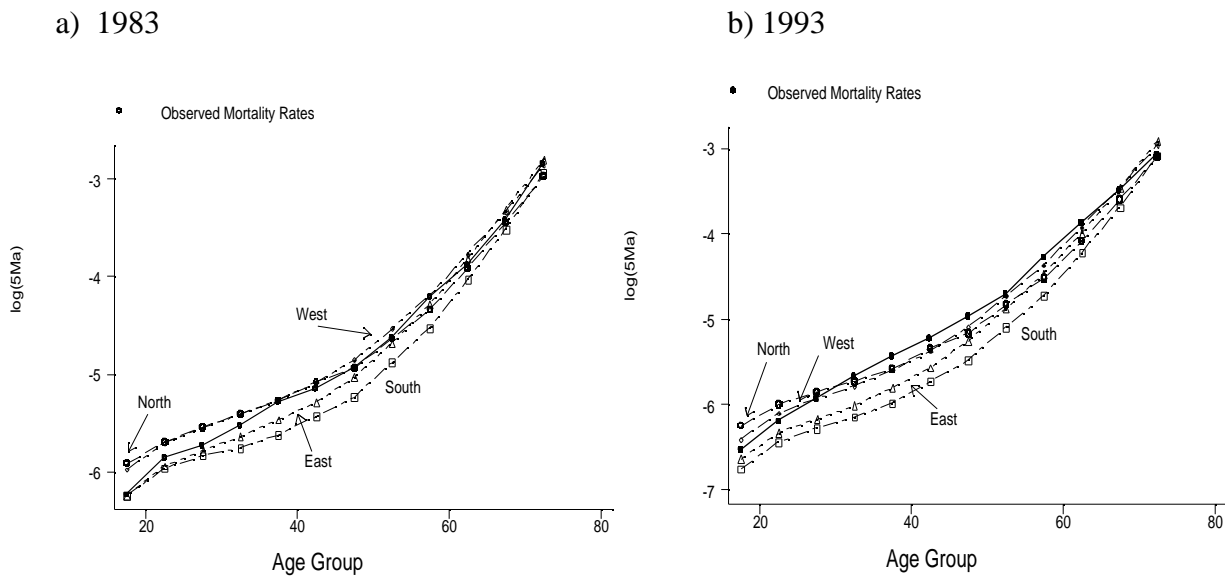
The proportion of brothers or sisters surviving by age of respondent is also clearly an indicator of survivorship – approximating the probability of survival from birth to the age of the respondents (Hill and Trussell 1977). Improved ways of using such data have been proposed (Timæus et al., 1997), in particular with respect to measuring maternal mortality (Graham et al., 1989), and the Demographic and Health Surveys have developed a sibling history approach to measuring adult mortality similar to the birth history approach to estimating child mortality (Rutenberg and Sullivan, 1991).

The Age Pattern of Mortality in Guatemala

The estimation methods outlined above provide different measures of adult mortality. The traditional intercensal survival method estimates survivorship ratios, as do survival of mother methods. The Preston-Bennett intercensal method estimates expectations of life at various ages, while the death adjustment methods provide a basis for a complete post-childhood life table and thus of any indicator desired. For comparison of

performance across methods, it is necessary to adopt a common indicator, and to convert all estimates into it. In this paper I will use the probability of dying between the ages of 15 and 60, $_{45}q_{15}$, as the common index. A model life table system is a convenient way of making the conversions. Figure 1 shows age-specific mortality rates for ages 15 to 75 for Guatemalan females based on registered deaths in 1983 in combination with the 1981 census age distribution (panel A) and 1993 in combination with the 1994 census age distribution (panel B) plotted on a log scale against age-specific rates from each of the four families of Coale-Demeny (1983) model life tables, using level 17 ($_{45}q_{15} = 0.257$) in 1983 and level 19 ($_{45}q_{15} = 0.205$) in 1993. The observed Guatemala schedule is more linear (on a log scale) than any of the Coale-Demeny families, but the West family gives the closest approximation. We will therefore use the Coale-Demeny “West” family of model life tables for conversion purposes.

Figure 1: Female Age-Specific Mortality Rates (Registered Deaths) in 1983 and 1993 for Ages 15 to 75 Compared to Coale-Demeny Model Patterns: Guatemala.



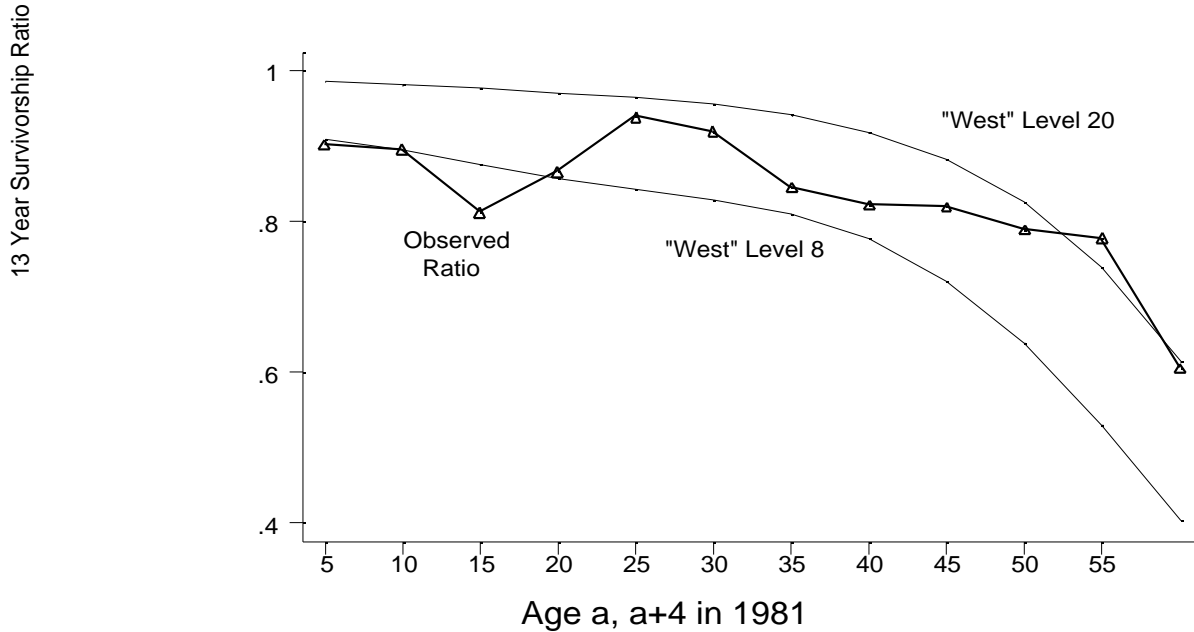
Estimation Results

Intercensal Survival Methods

Traditional intercensal survival cannot easily be applied to the 1981 and 1994 Guatemala censuses because the intercensal interval is 13 years and one month. The single year age distribution for 1994 has been used to create age groupings that closely approximate standard five year cohorts in 1981, namely age groups 13 to 17 (0 to 4 in 1981), 18 to 22 (5 to 9 in 1981), and so on. The resulting survivorship ratios cannot be conveniently chained together for summarization, since the numerators and denominators do not cancel. Nor can the ratios be directly compared with the Coale-Demeny model life tables. Approximate 13 year survivorship ratios have been calculated for Coale-Demeny “West” females for mortality levels 8 ($_{45}q_{15} = 0.5015$) and 20 ($_{45}q_{15} = 0.1788$). The

observed survivorship ratios for initial cohorts aged 5-9 to 60-64 in 1981 are plotted in Figure 2 with the ratios for these two models. The observed survivorship ratios are (with some irregularity) largely flat between ages 15-19 and 55-59, starting below level 8 and ending above level 20. The survivorship ratios appear to provide no basis whatever for arriving at an estimate of adult mortality for the intercensal period (and provide a warning that errors in census data may be substantial).

Figure 2: Survivorship Ratios between 1981 and 1994 Censuses. Female Population: Guatemala



Preston-Bennett (1983) Method

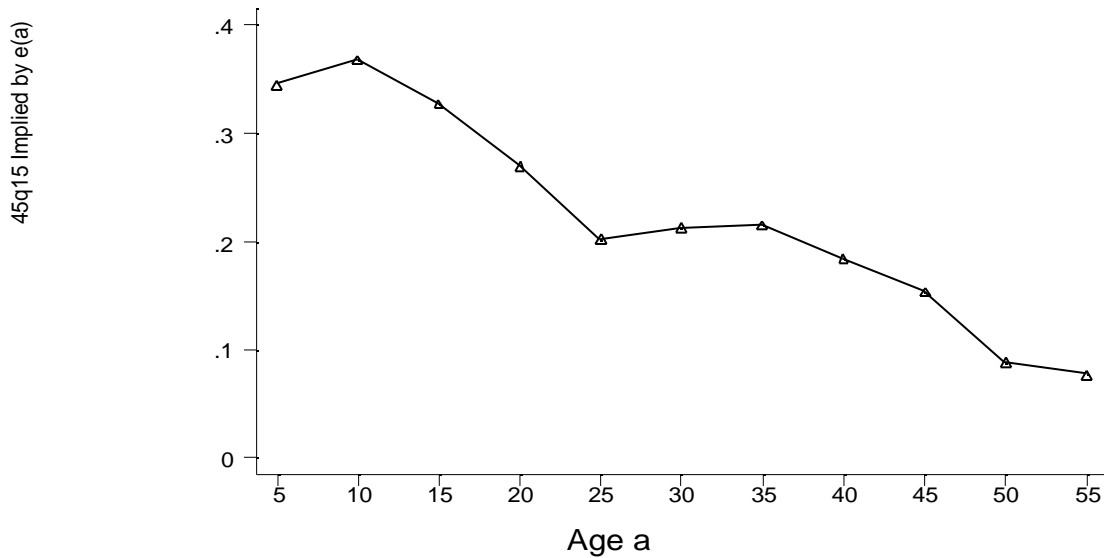
Age-specific growth rates for an intercensal period are used to convert a non-stable age distribution (typically an average of a first and second census age distribution) into the corresponding stationary or life table population, from which expectations of life at each age can be derived. This method uses only two age distributions, but can be applied regardless of the intercensal interval, since age-specific growth rates are as easy to calculate for non-integer as for integer intervals, and has the additional advantage of providing smoothing by cumulating values above each age a . The methodology is based on a discrete approximation of the general equation for the age distribution of a closed population:

$${}_5L_a = {}_5N_a * \exp(2.5 * {}_5r_a + \sum_{x=0}^{a-5} {}_5r_x) \quad (1)$$

Expectation of life at age a is then estimated by dividing the sum of ${}_5L_x$ values above age a by an approximation of ${}_5L_a$ based on one fifth of the average of ${}_5L_{a-5}$ and ${}_5L_a$.

Results of applying this method to the female population enumerated in Guatemala in 1981 and 1994 are shown in Figure 3 in the form of the $_{45}q_{15}$ values implied in the “West” family of model life tables by each value of $e(a)$. As age a increases, the implied risk of dying drops almost monotonically, from a value of 0.367 at age 10 to a value of 0.076 by age 55. Though somewhat less extreme than the individual cohort survivorship ratios, the method clearly provides no basis for arriving at a defensible single estimate of the level of adult mortality.

Figure 3: Application of Preston-Bennett Method: Female Population 1981 and 1994, Guatemala



Preston Integrated Method

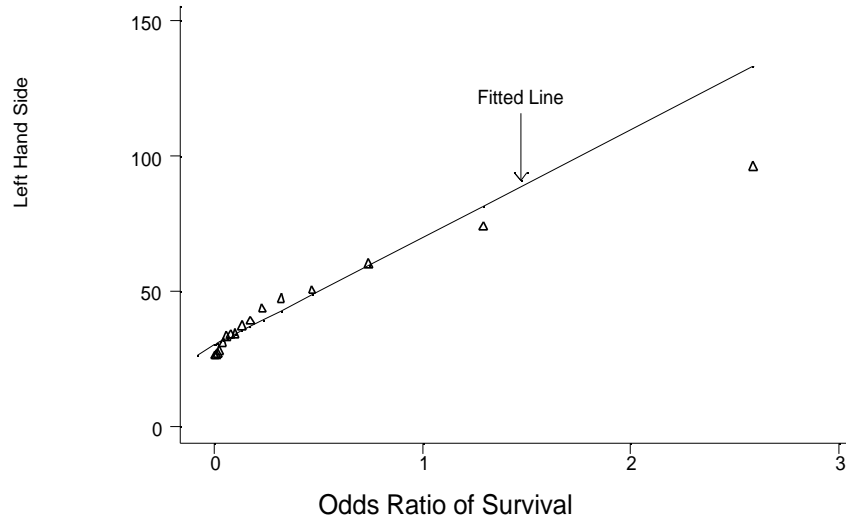
The Preston Integrated Method (Preston 1983) also uses the general equation for the age distribution of a closed population, but parameterizes mortality such that the survival odds ratio in the observed population is assumed to be a linear function of the survival odds ratio in a standard life table. In continuous notation,

$$\frac{p(5)}{c(a) \exp\left(\int_0^a r(y) dy\right)} = \frac{1}{b} + \frac{\gamma}{b} * \frac{p_s(5) - p_s(a)}{p_s(a)} \quad (2)$$

Where $c(a)$ is the proportion of the population age a , $r(y)$ is the instantaneous growth rate at age y , $p(5)$ is an estimate of the probability of surviving to age 5 in the observed population, $p_s(5)$ and $p_s(a)$ are probabilities of surviving to ages 5 and a respectively in the “standard” life table, b is the crude birth rate, and γ is a scale parameter, relating the observed and the standard life table survival odds ratios. The left hand side (based on the observed age distribution) and the right hand side (derived from the mortality standard) are linearly related, and should thus permit estimation of the birth rate b and the mortality

scale parameter $_$. Figure 4 shows the points for ages a from 5 to 70 using a “West” female model life table of level 18 as the standard. The relationship is clearly curvilinear. The shown fitted straight line (using a robust regression technique that underweights outliers (StataCorp 1999)) has an intercept of 30.4 (estimated b 32.9 per 1,000) and a slope of 39.8 (estimated $_ = 1.31$), implying higher mortality than the standard, with a $_{45}q_{15}$ of 0.281. However, given the curvilinear nature of the plot, trying to interpret the fit of a straight line is a hazardous undertaking.

FIGURE 4: Preston Integrated Method: 1981 and 1994 Censuses. Female Population, Guatemala



Death Distribution Methods

The distribution of deaths by age and the distribution of the population by age are linked via growth rates in various identities that provide a basis for consistency checks. The simplest relationship is that proposed by Brass (1975) for a stable population in his Growth Balance Equation:

(3)

$$\frac{N(a)}{N(a+)} = r + \frac{D(a+)}{N(a+)}$$

where $N(a)$ and $N(a+)$ are the number of entries into and the population of the age group a and over respectively, r is the stable population growth rate, and $D(a+)$ is the deaths at ages a and over. What the expression states is that the entry rate into the population $a+$ is equal to the exit rate from the population $a+$ plus the growth rate of the population $a+$ (constant at all ages in the case of a stable population). If deaths are reported with completeness c , assumed constant by age, relative to the population, and $Do(a+)$ is reported deaths at ages a and over,

(4)

$$\frac{N(a)}{N(a+)} = r + \frac{1}{c} * \frac{Do(a+)}{N(a+)}$$

A first question is whether the female population of Guatemala can be regarded as approximately stable. Inspection of the age-specific growth rates for the period 1981 to 1994 (not shown) shows that not only are there irregularities, with rather low growth at ages 20 to 30 and 45 to 60, but there is a systematic upward trend in the growth rate with age. Thus the basic assumption on which the Brass method is based does not hold.

Hill (1987) has extended the method to be applicable to a non-stable (but closed) population using data from two censuses, and observed growth rates:

(5)

$$\frac{N(a)}{N(a+)} - r_o(a+) = k + \frac{1}{c} * \frac{D_o(a+)}{N(a+)}$$

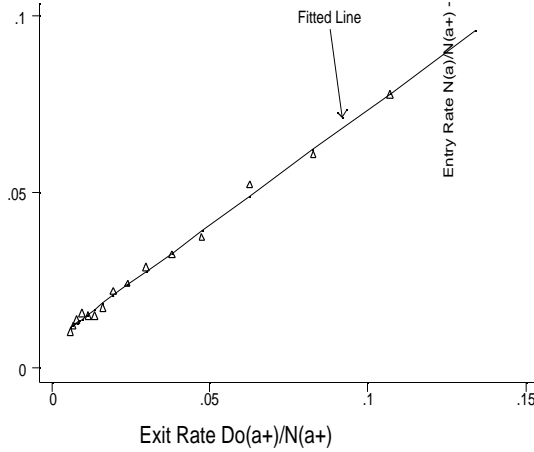
Where $r_o(a+)$ is the observed growth rate of the population a and over, and k is the error in the growth rate (assumed constant across ages), arising for instance from a systematic change in census coverage between the first and the second census. We can apply this method to the Guatemala data in two ways: by using registered deaths by age (available for the years 1983 to 1993), or by using household deaths reported in the 12 months before the 1994 census. The two ways differ in the extent to which the data reflect the age pattern of deaths over the intercensal period: in the first way, almost all the period is represented, whereas in the second, only the last year of the 13 year period is represented.

Figure 5 shows the plots for both applications. In both cases, a straight line fits the points very closely, suggesting that the different period coverage of the two sets of death data makes little difference. Using registered deaths, the intercept (interpreted as systematic error in the growth rate) is 0.00786, and the slope (interpreted as reciprocal of death coverage relative to average census coverage) is 0.655. If the error in the growth rate is attributed to a constant proportionate change in census coverage at all ages, that change is estimated to be a decline of coverage of 11 percent. Relative to coverage of the 1994 census, the slope estimates a coverage of deaths of 161 percent, that is, substantially more complete than the second census (and about 45 percent more complete than the first census). Using 1994 census deaths, the intercept is estimated as 0.00807 (decline of coverage of 12 percent) and the slope as 0.915 (coverage of deaths relative to the 1994 census 115 percent).

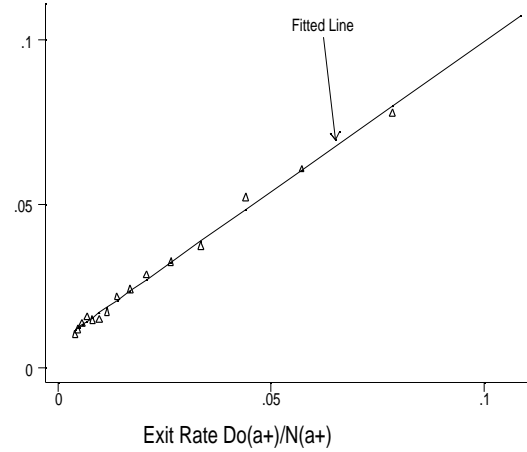
The large intercept indicates a major worsening of census coverage from 1981 to 1994. However, the slope of the registered deaths line, indicating a major excess of registered deaths over census populations, suggests substantial omission even in 1981. The 1994 deaths, recorded in households interviewed in the 1994 census, cannot be affected by major coverage errors, and sure enough, the excess of deaths over the expected average annual intercensal number relative to the 1994 population is only about 15 percent, which can largely be accounted for by the effects of population growth since it measures deaths relative to the average 1981-94 population.

FIGURE 5: Application of General Growth Balance Method : Female Population, Guatemala, 1981 to 1994

a) Registered Deaths 1983-93



b) Deaths in Year Before 1994 Census



Synthetic Method of Extinct Generations

Bennett and Horiuchi (1981) propose a methodology for estimating the coverage of death recording using the distribution of deaths by age and period age-specific growth rates. In a stationary population, the population of age a is by definition equal to the number of deaths that occur at age a and over, since everyone dies ultimately. Age-specific growth rates can be used to expand recorded deaths at each age to equal the number of deaths that would have occurred in a stationary population. The stationary population deaths can then be summed above each age a to estimate (on the basis of deaths and growth rates alone) the number of persons age a . Completeness of death recording relative to population recording can then be estimated as the ratio of the population estimate based on deaths to the population estimate based on census counts. Thus

(6)

$$N^{\$}(a) = \int_a^{\omega} D_o(y) * \exp\left(\int_a^y r(z) dz\right) dy$$

and

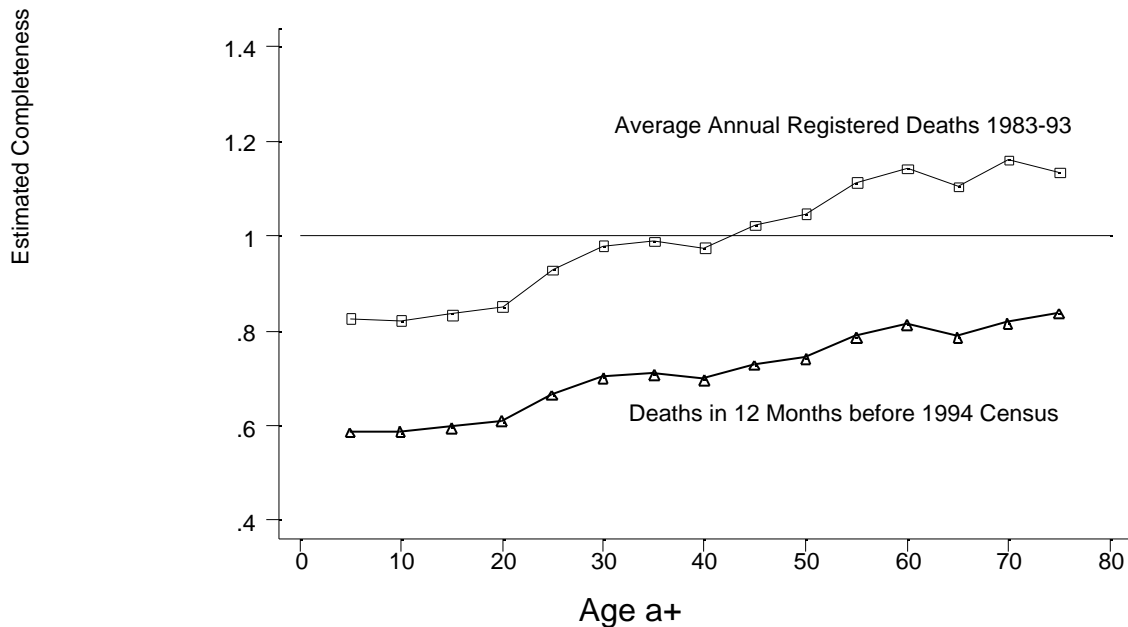
(7)

$$C = \frac{N^{\$}(a)}{N(a)}$$

Figure 6 shows the application of the Bennett-Horiuchi method to the 1981-1994 Guatemala data, using both registered and 1994 census deaths. The registered and census death series track each other very closely, with the registration series well above the census series, but in both cases the estimates of relative completeness of death

registration c rise consistently with age, for registered deaths from well below 1.0 at ages under 20 to around 1.2 at ages 60 and over. The series do not provide a clear basis for choosing adjustment factors. The likely problem is that the change in census coverage suggested by the growth balance methods has adversely affected the results of the Bennett-Horiuchi approach.

FIGURE 6: Application of Bennett-Horiuchi Method: Female Population, 1981 to 1994: Guatemala



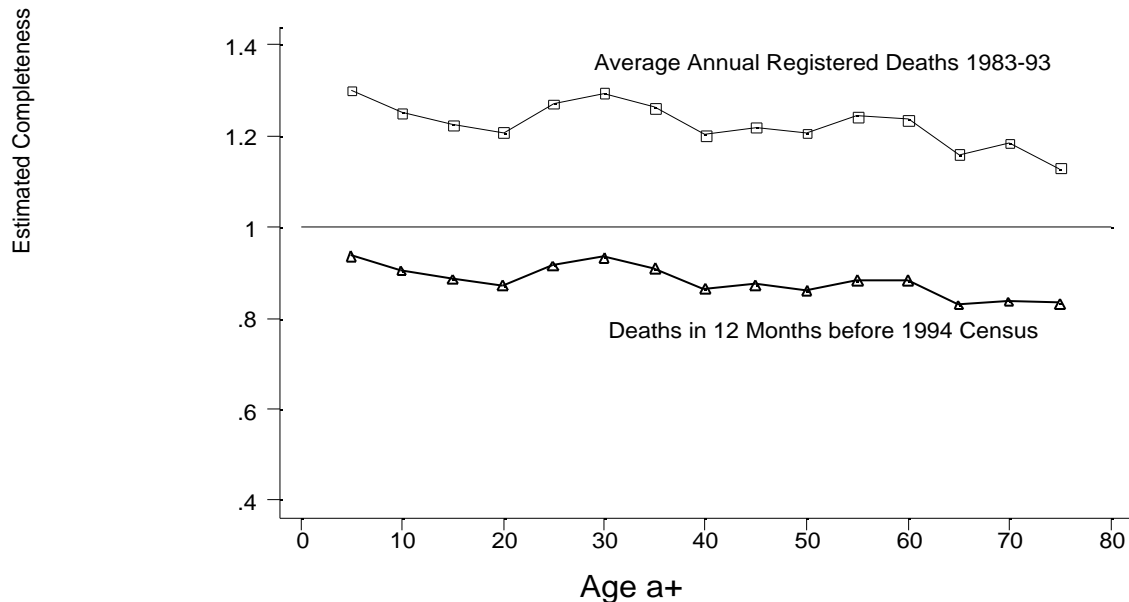
The possibility of census coverage change suggests a further use of the Bennett-Horiuchi method, reapplying the method after adjusting the census data for coverage change estimated by the General Growth Balance approach. Results are shown in Figure 7. The two series are considerably more consistent by age, though now tending to slope downward by age slightly.

Simulations of Performance of Death Distribution Methods in Presence of Errors

Typical applications of death distribution methods to developing country data are likely to face a number of types of data errors, of which changes in census coverage and systematic age misreporting are likely to be most important. Little is known about how the methods are affected by such errors. To examine this question, a simulated non-stable population of known mortality ("West" female level 15) has been projected for a five year period, and then subjected to age transfers between five year age groups and to change in coverage at observation at the beginning and end of the period. The age transfers were based on a matrix estimated by Bhat (1990) for India; three different age error simulations were used: with the same age transfers for both populations and deaths, with transfers only for the population, and with transfers only for the deaths. Change in

population coverage was a two percent decline for the second observation. For each simulated population, both the General Growth Balance (GGB) and the Bennett-Horiuchi

FIGURE 7 : Application of Bennett-Horiuchi Method: Female Population, 1981 to 1994: Guatemala: Censuses Adjusted on Basis of General Growth Balance



(BH) methods were applied. Adjustment factors in each case were based upon OLS for GGB, and the average completeness estimates across ages 5 to 75 for BH. In each case, a summary measure of adult mortality, $_{45}q_{15}$, has been calculated, using both the raw (in some cases distorted) data and the data after standard adjustment. Results are shown in Table 1.

It is evident that both GGB and BH give good estimates in the absence of data errors, within 1.5 and 2.5 percent on the summary measure. Age reporting errors of the type tried result in overestimates of mortality. For GGB, the overestimate is 7 percent if the errors affect both populations and deaths, 8 percent if the errors affect populations only, and 3 percent if the errors affect deaths only; corresponding errors for BH are 3 percent, 6 percent and minus 1 percent. A decline in coverage from census 1 to census 2 also results in overestimates: for GGB, 6 percent in the absence of age reporting errors and 7 percent with age reporting errors, and for BH, 13 percent both in the presence and in the absence of age reporting errors. The last two lines of Table 1 show results for a mixed strategy: obtaining an estimate of coverage change from GGB, adjusting the census

Table 1: Simulation Comparisons of Death Distribution Methods

Method	Error(s)	Observed _{45q15}	Estimated _{45q15}
“West” Level 15	True value	0.309	N/A
Growth Balance	No errors	0.309	0.314
	Age errors on both populations and deaths	0.313	0.331
	Age errors in populations only	0.321	0.338
	Age errors in deaths only	0.302	0.318
	No age errors, 2 nd pop 2% incomplete	0.312	0.328
	Age errors in both, 2 nd pop 2% incomplete	0.315	0.331
Bennett-Horiuchi	No errors	0.309	0.317
	Age errors on both populations and deaths	0.313	0.317
	Age errors in populations only	0.321	0.328
	Age errors in deaths only	0.302	0.307
	No age errors, 2 nd pop 2% incomplete	0.312	0.349
	Age errors in both, 2 nd pop 2% incomplete	0.315	0.349
	No age errs, 2 nd pop 2% incomp., GGB adj.	0.312	0.312
	Age errs in both, 2 nd pop 2% inc., GGB adj	0.315	0.309

populations to be consistent according to that estimate, and then applying BH to the adjusted data. This strategy with these simulated values is remarkably effective: an overestimate of 1 percent in the absence of age errors and a miniscule error in the presence of age errors in both populations and deaths.

The conclusions from this set of simulations (using only a single pattern of age misreporting) are that both GGB and BH work well in the absence of error, that both tend to overestimate mortality when ages of the living are exaggerated (GGB somewhat more so than BH) but that exaggeration of ages of the dead affects them less, that both tend to overestimate mortality when coverage declines from the first census to the second (BH much more so than GGB), and that the combined strategy of using GGB to adjust the populations before applying BH works remarkably well.

Summary Measure of Mortality from Death Distribution Methods, Guatemala, 1981 to 1994

Table 2 shows estimates of _{45q15} based on recorded deaths and populations by age, adjusted using GGB, BH and the combined strategy. Without adjustment, the registered deaths and the census deaths give very different estimates, probabilities of dying between 15 and 60 of 22 percent and 16 percent respectively. Within adjustment methods, the estimates vary very little by source of deaths (because each is scaled by age distribution information) but the variation across methods is large: estimates of _{45q15} of 15 percent from GGB, 22 percent from BH, and 17.5 percent from the combined strategy.

TABLE 2: Death Distribution Method Estimates of Adult Mortality, Guatemala, 1981 to 1994

Adjustment Method	Source of Deaths	Adjustment Factor	Estimated _{45q15}
No Adjustment	Registration 83-93	None	0.2197
	Census 93-94	None	0.1630
General Growth Bal	Registration 83-93	0.6551	0.1500
	Census 93-94	0.9149	0.1502
Bennett-Horiuchi	Registration 83-93	1.0041	0.2205
	Census 93-94	1.4083	0.2217
General Growth	Registration 83-93	0.7965*	0.1750
Bal. and Benn-Hor	Census 93-94	1.0706*	0.1745

* Net effect adjusting both 1994 population and deaths

Methods Based on Survival of Close Relatives

Survival of Mother (and Father)

The proportion of persons of a given age group with mother still alive is an indicator of mortality risk: other things being equal, the higher the risk, the lower the proportion surviving, and vice versa. The proportion surviving is also affected by the age distribution of the mothers at the time the cohort of respondents was born: the older the mothers, the lower the proportion surviving. Existing analytical methods (Brass and Hill 1973; Hill and Trussell 1977; United Nations 1983; Timæus 1991, 1992) use models of fertility, mortality and resulting age structure to calculate relationships between proportions of respondents of a given age group with mother alive and standard life table measures. Results of applying the standard United Nations Manual X (1983) analysis (including the time location of estimates using the procedure proposed by Brass and Bamgboye (1981)) to the 1987 DHS and 1994 Census proportions with mother surviving are shown in Table 3. The analysis has been restricted to reports from *female* respondents, partly because the DHS only provides data for female respondents, and partly because an analysis of the 1994 data by single year of age and sex shows puzzling, systematic deviations in reporting by sex of respondent, whereby the proportion of female respondents with mother surviving is nearly 10 percent lower than that for males (0.313 to 0.343 respectively) for respondents in their early 50s. That this effect is in some way related to age misreporting is indicated by the fact that the discrepancies are much larger for respondents reporting ages ending in digits 0 or 5 than for those reporting other terminal digits (see Appendix Figure 1). It should also be noted that the 1987 survey limited data collection to ever-married women only. To the extent that age at marriage and survival of mother may be related, the results may not represent the national mortality level.

TABLE 3: Adult Mortality Estimates from Proportions With Surviving Mother: 1987 DHS and 1994 Census

Age Group (N-5,N)	Prop. Mother Alive 1987	(25+N)/(25)	Derived ${}_{45}q_{15}$	Ref Period Before Survey	Prop. Mother Alive 1994	(25+N)/(25)	Derived ${}_{45}q_{15}$	Ref Period Before Survey
15-19	0.9159	0.9108	0.2488	1980.0	0.9329	0.9288	0.2123	1986.6
20-24	0.8817	0.8796	0.2462	1978.2	0.8828	0.8808	0.2436	1984.7
25-29	0.8427	0.8455	0.2305	1976.8	0.8289	0.8314	0.2515	1983.2
30-34	0.7628	0.7707	0.2515	1975.5	0.7654	0.7734	0.2488	1982.0
35-39	0.6265	0.6349	0.3038	1974.1	0.6811	0.6941	0.2462	1981.1
40-44	0.5643	0.5751	0.2541	1973.8	0.5762	0.5885	0.2410	1980.5
45-49	N/A	N/A	N/A	N/A	0.4621	0.4640	0.2227	1980.3

A constant M , mean age difference between mothers and respondents, of 27.0 years has been used throughout.

Timæus (1991) has proposed a method for estimating adult mortality by survival of parent since first marriage. Early Demographic and Health Surveys (among them the 1987 Guatemala survey) included questions on survival of mother and father and on whether each was alive at the time of the respondent's first marriage. Timæus developed a method for arriving at mortality estimates from such data. Of particular interest is the analysis of proportions with deceased parent since marriage: the reference period of the estimates is more recent than for overall parental survival, and any systematic bias due to adoption of young children should not affect data from first marriage onwards. Disadvantages of the method are that it requires more assumptions (independence of age at marriage and parental survival, for example) and requires control not only for the ages of parents at the time of respondents' birth, but also a control for the distribution of respondents by age at marriage. This control cannot be made until most first marriages have occurred, so data for respondents under age 25 cannot be used.

Application of the method to data from the 1987 Guatemala DHS is shown in Table 4. A mean age of mother at birth of respondents of 27 years, and a mean age at first marriage of 20.75 years, have been used.

TABLE 4: Estimation of Adult Female Mortality from Proportions Whose Mother Was Still Alive Having Been Alive at Respondent's First Marriage. Guatemala, 1987 DHS

Age Group of Respondents	N	Proportion Mother Still Alive	Estimated (25+N)/(45)	Reference Date	"West" Level	Implied _{45Q15}
25 to 29	30	0.9328	0.9107	1984.1	16.9	0.2593
30 to 34	35	0.8628	0.7881	1982.3	12.6	0.3697
35 to 39	40	0.7158	0.7408	1980.9	16.4	0.2724
40 to 44	N/A	0.6607	N/A	N/A	N/A	N/A

The estimates are not very consistent (the very heavy mortality estimate from (60)/ (45), based on reports of respondents aged 30 to 34 and 35 to 39, is affected by the large weight the method puts on the proportion for respondents aged 35 to 39, an age group with a low proportion with mother surviving in the all respondents analysis) and suggest generally heavier mortality than the all respondents analysis. This heavier mortality could be the result of the method purging bias due to an adoption effect.

Intersurvey Survival of Mother

Where information on survival of mother is available from two successive censuses or surveys, the change in proportion with mother surviving for a cohort of respondents between one survey and the next reflects mortality risks of the intersurvey period alone. A variety of approaches have been proposed to estimate such risks (Zlotnik and Hill, 1980; Timæus, 1986). It is convenient to obtain survivorship ratios from cohort changes directly. Simulations have been used to develop cohort-specific analysis for this paper. There are two substantial advantages to the cohort-specific approach. First, the ratio of proportion with mother surviving at a second observation to that at the first observation is unaffected by any pre-existing error (such as might be caused by an adoption effect) that affects both proportions equally. Second, if fertility has changed in the past and information on the changes is available, the distribution of the respondents' cohort by age of mother at the time of their birth can be incorporated for each specific cohort. On the basis of the simulations, an estimating equation of the following form was developed for a 5 year interval:

$$\frac{I_{35+a}}{I_{30+a}} = \alpha_a^5 + \beta_a^5 * \overline{M}_c + \gamma_a^5 * \frac{PMS_{a+5,a+10}^{t+5}}{PMS_{a,a+5}^t} + \delta_a^5 * \overline{M}_c * \frac{PMS_{a+5,a+10}^{t+5}}{PMS_{a,a+5}^t} \quad (8)$$

and of the following form for a 10 year interval:

$$\frac{I_{40+a}}{I_{30+a}} = \alpha_a^{10} + \beta_a^{10} * \overline{M}_c + \gamma_a^{10} * \frac{PMS_{a+10,a+15}^{t+10}}{PMS_{a,a+5}^t} + \delta_a^{10} * \overline{M}_c * \frac{PMS_{a+10,a+15}^{t+10}}{PMS_{a,a+5}^t} \quad (9)$$

Coefficients for both equations are shown in Appendix Table 1.

Summary measures of adult mortality that incorporate some smoothing can be obtained by chaining the five year or ten year survivorship ratios together. For example, in the case of a five-year interval, and youngest and oldest cohorts aged 15 to 19 and 40 to 44 respectively at first survey, multiplying the survivorship ratios together and subtracting the result from one estimates $_{30}q_{45}$ for the intersurvey period.

In the case of Guatemala, we have data on survivorship of mother for respondents of age groups 15-19 to 40-44 from the 1987 DHS, and for all age groups from the 1994 census. It should be noted that the 1987 data are for ever married women only: if marriage and maternal survival are related, the proportions with mother surviving will not be representative of the population as a whole, especially for younger respondents. The intersurvey interval is nearly 7 years in this case. To approximate a five year interval, proportions with mother surviving for 1989 were estimated age group by age group by linear interpolation between the 1987 and 1994 values. Registered births by age from 1948 were then used to estimate cohort-specific values of M . Equation (8) was then used to estimate five year survivorship ratios, which were then chained multiplicatively to estimate $_{30}q_{45}$ for the period 1989 to 1994. Results are shown in Table 5.

TABLE 5: Application of Intersurvey Maternal Survival Analysis, Guatemala 1987 to 1994.

Age group $a, a+5$	Prop. with Mother Alive 1987	Prop. with Mother Alive 1994	Interpolated Prop. with Mother Alive 1989	"Cohort" Maternal Survivorship Ratio by 1987 Age Group	Cohort M	$(35+a)/$ $(30+a)$
15 to 19	0.9359	0.9329	0.9207	0.9588	26.80	0.9669
20 to 24	0.8828	0.8828	0.8820	0.9398	27.05	0.9502
25 to 29	0.8289	0.8289	0.8387	0.9125	27.10	0.9279
30 to 34	0.7628	0.7654	0.7635	0.8921	26.90	0.9064
35 to 39	0.6265	0.6811	0.6421	0.8974	26.80	0.9146
40 to 44	0.5643	0.5762	0.5677	0.8139	(26.80)	0.8088
45 to 49	N/A	0.4621	N/A	N/A	N/A	N/A

The chained 5 year survivorship ratios estimate $_{30}q_{45}$ as 0.4285, equivalent to a $_{45}q_{15}$ value of 0.1513 in the "West" model life tables, somewhat lower than the intercensal estimates based on the distributions of deaths by age. It should be remembered that the time periods covered by these estimates are not the same, however: the death distribution estimates are an average over the period 1981 to 1994, whereas the intersurvey maternal survival estimate is for the period 1989 to 1994.

Survivorship of Sisters

The 1995 DHS included a complete sibling history for every respondent. Although primarily intended to provide estimates of maternal mortality, the sibling history also provides estimates of overall mortality, at least for the range of ages covered by substantial sibling experience. Mortality rates for defined time periods can be calculated directly from the sibling history data, since they provide both deaths by age and exposure time by age (Rutenberg and Sullivan 1991). However, events tend to be fairly sparse on the basis of a household survey, so estimates are calculated for quite long time periods, in this case the period 0 to 6 years before the survey. Age-specific mortality rates for females for age groups 15-19 to 45-49 have been calculated, and used to calculate the summary measure of mortality $_{35}q_{15}$. Stanton et al. (2000) quote this value as 0.064, corresponding to a value of $_{45}q_{15}$ of 0.1345 in the "West" family of model life tables. The reference period for this estimate is 1988 to 1995, very similar to that of the intersurvey maternal survival estimate, though the estimate itself is some 15 percent lower.

Discussion

Despite the fact that death registration in Guatemala is reputed to be of good quality, it is clear that it does not provide a "gold standard" against which indirect methods of adult mortality estimation can be measured. The analyses presented above clearly show that there are major problems with census enumeration, and that it is not possible to arrive at firm conclusions about levels of adult mortality. An additional unknown, not considered here in detail, is migration: it is possible (though internal patterns of results do not suggest it) that migration has affected the intercensal and death distribution methods. Even given these caveats, it is possible to compare estimates from various methodologies, using a variety of data sources, and draw some conclusions about the performance of the methodologies and about likely levels of adult mortality.

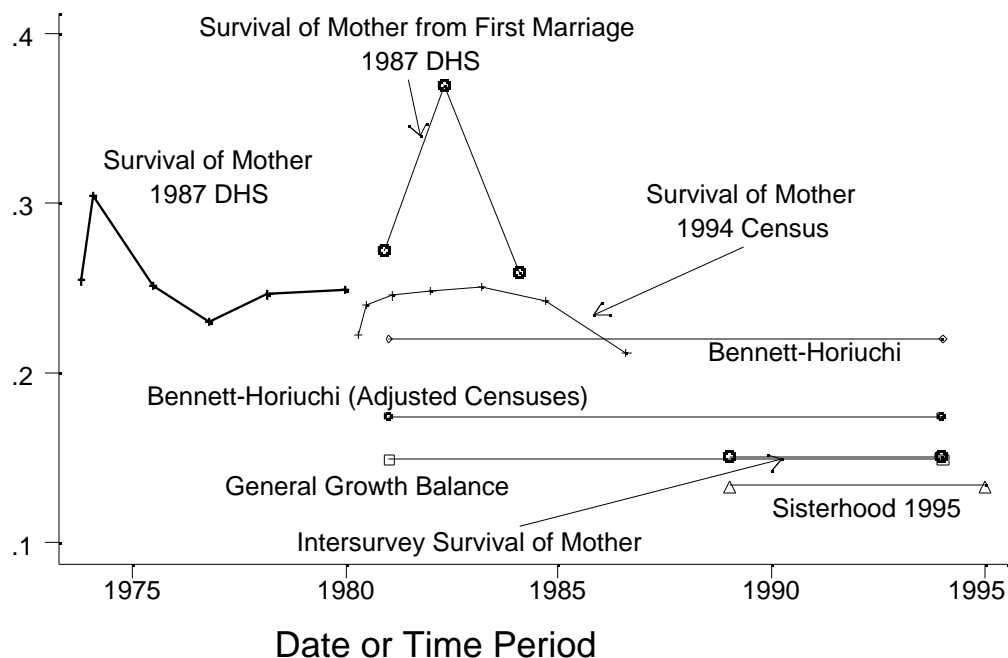
The range of estimates for the period 1981 to 1994 is very wide. In terms of the summary indicator $_{45}q_{15}$, the estimates range from a low of about 0.08 (Preston-Bennett intercensal survival for respondents 50 and over) to a high of 0.50 (traditional intercensal survival, respondents under age 20 in 1981). The intercensal survival methods show so much variability by age as to be useless for arriving at a best estimate.

The death distribution methods, assuming a closed but non-stable population, give much more consistent results, with $_{45}q_{15}$ estimates ranging from 0.15 (General Growth Balance) to 0.22 (Bennett-Horiuchi). The range using unadjusted data is very similar: 0.22 using registered deaths and the two censuses, and 0.16 using the 1994 census and deaths in the preceding year. Using a double strategy – General Growth Balance to adjust the censuses for consistency of coverage, and Bennett-Horiuchi to assess death recording – gives an intermediate estimate of 0.175, regardless of whether registered deaths or household deaths reported to the 1994 census are used. It is reassuring that the census question on deaths in households appears to have given results equivalent to those from registered deaths in this application.

The methods based on survival of relatives give results that are somewhat more consistent than the intercensal survival approaches, but less consistent than the death distribution methods. Proportions with surviving mother in the 1987 DHS and 1994 censuses produce estimates of ${}_{45}q_{15}$ in the range of 0.21 to 0.30, proportions with surviving mother among those with a mother alive at first marriage give estimates ranging from 0.26 to 0.37, and intersurvey survival of mother (chaining individual survivorship ratios) gives an estimate of around 0.15. Survival of sisters, from sibling histories collected by the 1995 DHS, give an estimate for the period 1988 to 1995 equivalent in the “West” model life table to a ${}_{45}q_{15}$ of 0.135.

The various estimates of adult mortality are shown in Figure 8 in terms of the summary indicator ${}_{45}q_{15}$.

FIGURE 8: Comparison of Death Distribution and Survival of Relatives Estimates of Adult Female Mortality in Guatemala, 1975 to 1995



The adult female mortality estimates derived from survival of mother appear to show some downward trend over the period from 1975 to the late 1980s, but the mortality levels are higher than most alternative estimates, particularly in the case of the survival of mother since first marriage method. As suggested by Chackiel and Orellana (1985), the dating of these estimates may be problematic. Sisterhood gives the lowest mortality estimates, though for late in the period. The death distribution methods cluster in the middle, together with the intersurvey estimate derived from survival of mother. In view of the simulation results, it seems reasonable to prefer the Bennett-Horiuchi method results after adjusting the census counts to approximate consistent coverage, though

despite the range of methods applied, the conclusion continues to have substantial uncertainty around it.

Conclusion

Despite the number of methods and the wide range of data available, a final estimate of adult mortality with narrow confidence bounds remains elusive in Guatemala. It is reasonably clear that the census enumerations have serious problems, with coverage apparently below that of death registration. Simulation suggests that a combined strategy of using an age pattern of deaths in combination with census counts, and applying both General Growth Balance and Bennett-Horiuchi methods of analysis, may be a robust strategy. It appears to give sensible, if not definitive, results in the case of Guatemala. Another conclusion is that the inclusion of a question on household deaths in a national census can also be a satisfactory alternative to death registration data: in the case of Guatemala, the choice of source of data on the age pattern of deaths made only a negligible difference to resulting estimates; choice of method had a much more important impact.

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APPENDIX

TABLE A1: Coefficients for Estimating Lifetable Survivorship Ratios from Maternal Survivorship Ratios

Initial Age Group of Cohort $a, a+5$	Intersurvey Interval 5 Years				Intersurvey Interval 10 Years			
	a	a	$(a$	a	a	a	$(a$	a
10 to 14	-0.2911	0.01380	1.2685	-0.0129	-0.3935	0.01642	1.3361	-0.0141
15 to 19	-0.3131	0.01767	1.2806	-0.0164	-0.5857	0.02323	1.5032	-0.0199
20 to 24	-0.6537	0.02755	1.6088	-0.0257	-0.8599	0.03131	1.7403	-0.0262
25 to 29	-0.8460	0.03378	1.7808	-0.0310	-1.1278	0.03731	1.9312	-0.0284
30 to 34	-1.1902	0.04056	2.0767	-0.0353	-1.2013	0.03740	1.8573	-0.0221
35 to 39	-1.1152	0.03740	1.9168	-0.0288	-1.1308	0.03351	1.5626	-0.0095
40 to 44	-1.1451	0.03548	1.8139	-0.0217	-0.9953	0.02808	1.1633	0.0046

FIGURE A1: Ratios of Proportions with Mother Alive for Male Respondents to Female Respondents by Single Years of Age: Guatemala 1994 Census

Ratio of Male to Female Proportions

